ocean explorer
www.oceanexplorer.noaa.gov

# The NOAA Ship *Okeanos Explorer*

NOAA Ship *Okeanos Explorer*: America's Ship for Ocean Exploration. Image credit: NOAA. For more information: *http://oceanexplorer.noaa.gov/okeanos/welcome.html*

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## Why Do We Explore?

*An essential component of the NOAA Office of Ocean Exploration and Research mission is to enhance understanding of science, technology, engineering, and mathematics used in exploring the ocean, and build interest in careers that support ocean-related work. To help fulfill this mission, the* Okeanos Explorer *Education Materials Collection is being developed to encourage educators and students to become personally involved with the voyages and discoveries of the* Okeanos Explorer*—America's first Federal ship dedicated to Ocean Exploration. Leader's Guides for Classroom Explorers focus on three themes: "Why Do We Explore?" (reasons for ocean exploration), "How Do We Explore?" (exploration methods), and "What Do We Expect to Find?" (recent discoveries that give us clues about what we may find in Earth's largely unknown ocean). Each Leader's Guide provides background information, links to resources, and an overview of recommended lesson plans on the Ocean Explorer Web site (*http://oceanexplorer.noaa.gov*). An Initial Inquiry Lesson for each of the three themes leads student inquiries that provide an overview of key topics. A series of lessons for each theme guides student investigations that explore these topics in greater depth. In the future additional guides will be added to the Education Materials Collection to support the involvement of citizen scientists.*

*This is the Leader's Guide for the "Why Do We Explore?" theme. Lessons for this theme guide classroom inquiries into key topics of Ocean Exploration, Energy, Climate Change, Human Health, and Ocean Health.*

### Background Information

"We know more about the dead seas of Mars than our own ocean."

~ Jean-Michel Cousteau

In fact, our current estimation is that 95% of Earth's ocean is unexplored. At first, this may be hard to believe, particularly if we look at recent satellite maps of Earth's ocean floor. These maps

### Seven Modern Reasons for Ocean Exploration

Ocean exploration supports and enhances the work of many individuals and organizations working on America's key science issues, including:

- ***Climate Change*** – The ocean has a major influence on weather and climate, but we know very little about deep-ocean processes that affect climate.
- ***Energy*** – Ocean exploration contributes to the discovery of new energy sources, as well as protecting unique and sensitive environments where these resources are found.
- ***Human Health*** – Expeditions to the unexplored ocean almost always discover species that are new to science, and many animals in deep-sea habitats have been found to be promising sources for powerful new antibiotic, anti-cancer and anti-inflammatory drugs.
- ***Ocean Health*** – Many ocean ecosystems are threatened by pollution, overexploitation, acidification and rising temperatures. Ocean exploration can improve understanding of these threats and ways to improve ocean health.
- ***Research*** – Expeditions to the unexplored ocean can help focus research into critical areas that are likely to produce tangible benefits.
- ***Innovation*** – Exploring Earth's ocean requires new technologies, sensors and tools and the need to work in extremely hostile environments is an ongoing stimulus for innovation.
- ***Ocean Literacy*** – Ocean exploration can help inspire new generations of youth to seek careers in science, and offers vivid examples of how concepts of biology, physical science, and earth science are useful in the real world.

**For recommended Lesson Plans about Ocean Exploration, please see page 13.**

seem to show abyssal plains, shelves, trenches, sea mountains and ocean ridges, seemingly in considerable detail. But satellites can't see below the ocean's surface. The "images" of these features are estimates of the ocean floor based on the height of the ocean's surface, which varies because the pull of gravity is affected by seafloor features. And, if we consider the scale of these maps, it is easy to see how some things might be missed. To show our planet's entire ocean, a typical wall map has a scale of about 1 cm = 300 km. At that scale, the dot made by a 0.5 mm pencil represents an area of over 60 square miles! The reality is that most of the ocean floor has never been seen by human eyes.

### Many Reasons to Explore

On February 17, 1977, scientists aboard the deep-diving submersible *Alvin* made one of the most significant scientific discoveries of the last century: a totally new ecosystem—tubeworms, clams and other strange animals living in ecosystems based on chemicals instead of sunlight. These animals were "extremophiles," thriving at the edge of scalding hydrothermal vents, surrounded by near-freezing seawater, total darkness, and water pressure more than 275 times greater than the pressure at sea level. Since 2001, expeditions from NOAA's Ocean Exploration Program have reported many other unexpected events and many new species in little-known parts of Earth's ocean. Fascinating as these discoveries are, scientific discovery is only one of the reasons for ocean exploration.

Historically, explorers have been driven by a variety of motives. For some, the primary reason to explore was to expand their knowledge of the world. For others, economic interests provided powerful incentives, and many expeditions have launched on such missions as finding a sea route to access the spices of Asia, or quests for gold, silver, and precious stones. Political power and the desire to control large empires motivated other explorations, as did the desire to spread religious doctrines. In the case of space exploration, additional reasons have been offered, including understanding our place in the cosmos, gaining knowledge about the origins of our solar system and about human origins, providing advancements in science and technology, providing opportunities for international collaboration, and keeping pace with other nations involved in developing space technology. The first ocean exploration for the specific purpose of scientific research is often considered to be the voyage of the HMS *Challenger*, conducted between 1872-1876 (visit http://oceanexplorer.noaa.gov/

explorations/03mountains/background/challenger/challenger.html and http://www.coexploration.org/hmschallenger/html/AbouttheProject.htm for more information about the *Challenger* expedition and comparisons with modern oceanographic exploration).

*Okeanos Explorer*'s prominent VSAT (Very Small Aperture Terminal) dome enables satellite communications between explorers ashore and afloat and provides multiple high-definition video streams for widespread dissemination. Image credit: NOAA.

***Okeanos Explorer* Vital Statistics:**

Commissioned: August 13, 2008; Seattle, Washington
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 46, including crew and mission support
Operations: Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA's Office of Marine and Aviation Operations (OMAO); Mission equipment operated by NOAA's Office of Ocean Exploration and Research

For more information, visit http://oceanexplorer.noaa.gov/okeanos/welcome.html.

### NOAA Ship *Okeanos Explorer*

On August 13, 2008, the NOAA Ship *Okeanos Explorer* was commissioned as "America's Ship for Ocean Exploration;" the only U.S. ship whose sole assignment is to systematically explore our largely unknown ocean for the purposes of discovery and the advancement of knowledge. The ship was originally one of the Navy's T-AGOS (Tactical Auxiliary General Ocean Surveillance) class vessels, and as the former USNS *Capable,* was used to gather underwater acoustical data.

To fulfill its mission, the *Okeanos Explorer* has specialized capabilities for finding new and unusual features in unexplored parts of Earth's ocean, and for gathering key information that will support more detailed investigations by subsequent expeditions. These capabilities include:

- Reconnaissance within a search area to locate unusual features or anomalies;
- Underwater robots (remotely operated vehicles, or ROVs) that can investigate anomalies as deep as 6,000 meters;
- Underwater mapping using multibeam sonar, capable of producing high-resolution maps of the seafloor to depths of 6,000 meters; and
- Advanced broadband satellite communication

Capability for broadband telecommunications provides the foundation for "telepresence," technologies that allow people to observe and interact with events at a remote location. This allows live images to be transmitted from the seafloor to scientists ashore, educators and media, and opens new educational opportunities, which are a major part of the *Okeanos Explorer's* mission for advancing knowledge. In addition, telepresence makes it possible for exploration activities to be controlled by scientists in shore-based Exploration Command Centers. In this way, scientific expertise can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions.

## Why Ocean Exploration Is Important Today

Curiosity, desire for knowledge, and quest for adventure continue to motivate modern explorers. But today, there are additional reasons to explore Earth's ocean, including climate change, energy, human health, ocean health, innovation, research and ocean literacy.

The black and white photograph of Muir Glacier was taken on August 13, 1941; the color photograph was taken from the same vantage on August 31, 2004. Between 1941 and 2004 the glacier retreated more than twelve kilometers (seven miles) and thinned by more than 800 meters (875 yards). Ocean water has filled the valley, replacing the ice of Muir Glacier; the end of the glacier has retreated out of the field of view. The glacier's absence reveals scars where glacier ice once scraped high up against the hillside. In 2004, trees and shrubs grew thickly in the foreground, where in 1941 there was only bare rock. Image credit: National Snow and Ice Data Center, W. O. Field, B. F. Molnia.
*http://nsidc.org/data/glacier_photo/repeat_photography.html*

## Climate Change

Since the middle of the 1800's, Earth's average temperature has warmed by about 1°F. This doesn't sound like much of a change, but it is important to realize that Earth's average temperature is now warmer than it has been at any time since at least 1400 AD. We say "at least" because 1400 AD is as far back as scientists have good estimates of temperatures. Other evidence suggests that Earth's temperature is warmer now than it has been in many thousands of years, maybe nearly 100,000 years. It is also important to remember that most averages include numbers that are higher and lower than the "average" value. So the warming in some areas can be much higher than 1°F, while other areas may actually be cooler. Debate continues about the causes of climate change and the relative importance of long-term climate cycles, greenhouse gases, and other factors; but it is clear that:

- Mountain glaciers are melting;
- Polar ice is decreasing;
- Springtime snow cover has reduced;
- Ground temperature has been increasing in many areas; and
- Sea level has risen by several inches in the last 100 years.

Global climate is strongly influenced by interactions between Earth's atmosphere and ocean, but these interactions are complex and poorly understood. While the deep-ocean might seem far removed from the atmosphere, one of the most significant climatic influences results from the "deep-ocean thermohaline circulation" (See the Diving Deeper section on page 18 for more information about the THC). The causes and effects of the THC are not fully known, but we do know that it affects almost all of the world's ocean and plays an important role in transporting dissolved oxygen and nutrients. For these reasons, the deep-ocean THC is often called the "global conveyor belt." We also know that the part of the THC that is the Gulf Stream is at least partially responsible for the fact that countries in northwestern Europe (Britain and Scandinavia) are about 9°C warmer than other locations at similar latitudes. Recent changes in the Arctic climate have led to growing concerns about the possible effects of these changes on the deep-ocean THC. Dense water sinking in the North Atlantic Ocean is one of the principal forces that drives the circulation of the global conveyor belt. Since warmer temperatures and increased freshwater inflow from melting ice cause seawater density to decrease, these changes could also weaken the global conveyor belt.

Trends toward a warmer climate are having impacts in the tropics as well. A major concern is the impact of higher temperatures on coral reefs. In the Caribbean, surveys of 302 sites between 1998 and 2000 show widespread recent mortality among shallow- ($\leq$ 5m depth) and deep-water (> 5m depth) corals (Kramer, 2003). Many scientists believe that the widespread decline of coral reefs is the result of accumulating stresses, one of which is increased water temperature.

There are many other potential impacts of changing climate, ranging from the possible extinction of species such as the polar bear to year-round access to sea routes through the Arctic. Ocean exploration can provide some of the essential knowledge about ocean-atmosphere interactions that is needed to understand, predict, and respond to these impacts.

**For recommended Lesson Plans about Climate Change, please see page 13.**

### Energy

> "For kicks, oceanographer William P. Dillon likes to surprise visitors to his lab by taking ordinary-looking ice balls and setting them on fire. 'They're easy to light. You just put a match to them and they will go,' says Dillon, a researcher with the U.S. Geological Survey (USGS) in Woods Hole, Mass. If the truth be told, this is not typical ice. The prop in Dillon's show is a curious and poorly known structure called methane hydrate."
>
> from "The Mother Lode of Natural Gas"
> by Rich Monastersky
>
> http://www.sciencenews.org/sn_arch/11_9_96/bob1.htm

Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials. Methane is produced in many environments by a group of Archaea known as the methanogenic Archaeobacteria. These Archaeobacteria obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep-ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form. Besides providing entertainment for oceanographers, methane hydrate deposits are significant for several other reasons:

- The U.S. Geological Survey has estimated that on a global

Iceworms (*Hesiocaeca methanicola*) infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald. *http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg*

scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined.

- Methane hydrates can decompose to release large amounts of methane which is a greenhouse gas that could have (and may already have had) major consequences to the Earth's climate.
- Sudden release of pressurized methane gas may cause submarine landslides which in turn can trigger catastrophic tsunamis.
- Methane hydrates are associated with unusual and possibly unique biological communities containing previously unknown species that may be sources of beneficial pharmaceutical materials.

While potential benefits as an alternative energy source are exciting, methane hydrates may also cause big problems. Although methane hydrates remain stable in deep-sea sediments for long periods of time, as the sediments become deeper and deeper they are heated by the Earth's core. Eventually, temperature within the sediments rises to a point at which the clathrates are no longer stable and free methane gas is released (at a water depth of 2 km, this point is reached at a sediment depth of about 500 m). The pressurized gas remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. If the overlying sediments are disrupted by an earthquake or underwater landslide, the pressurized methane can escape suddenly, producing a violent underwater explosion that may result in disastrous tsunamis, often called "tidal waves" which is misleading since they have nothing to do with tides.

The release of large quantities of methane gas can have other consequences as well, since methane is one of the so-called "greenhouse gases." In the atmosphere, these gases allow solar radiation to pass through but absorb heat radiation that is reflected back from the Earth's surface, thus warming the atmosphere. Many scientists have suggested that increased carbon dioxide in the atmosphere produced by burning fossil fuels is causing a "greenhouse effect" that is gradually warming the atmosphere and the Earth's surface. A sudden release of methane from deep-sea sediments could have a similar effect, since methane has more than 30 times the heat-trapping ability of carbon dioxide.

In 1995, Australian paleoceanographer Gerald Dickens suggested that a sudden release of methane from submarine


Deep Submersible Vehicle ALVIN being lifted onto the deck of R/V ATLANTIS after a dive. The 2003 Windows to the Deep expedition conducted seven dives using Alvin to explore the ecology, physics, and chemistry of seafloor methane seeps on the Blake Ridge and Carolina Rise (southeastern U.S. continental margin). Image credit: NOAA.
*http://www.photolib.noaa.gov/bigs/expl0127.jpg*

On the Blake Ridge and Carolina Rise, the gas hydrate deposits are typically deeply buried in the sediments. Here, the DSV Alvin's manipulator arms are being used to obtain push core samples from sediments close to a gas hydrate deposit. Image credit: WHOI.
*http://oceanexplorer.noaa.gov/explorations/03windows/logs/jul30/media/backgroundpushcore_600.jpg*

**For recommended Lesson Plans about Energy and Methane Hydrates, please see page 14.**

sediments during the Paleocene epoch (at the end of the Tertiary Period, about 55 million years ago) caused a greenhouse effect that raised the temperatures in the deep-ocean by about six degrees Celsius. The result was the extinction of many deep-sea organisms known as the Paleocene extinction event. More recently, other scientists have suggested that similar events could have contributed to mass extinctions during the Jurassic period (183 million years ago), as well as to the sudden appearance of many new animal phyla during the Cambrian period (the "Cambrian explosion," about 520 million years ago).

Besides methane hydrates, regions such as the Gulf of Mexico produce significant quantities of petroleum. Often, the presence of hydrocarbons at the surface of the seafloor is accompanied by "cold-seep communities" which are biological communities that derive their energy from gases (such as methane and hydrogen sulfide) and oil seeping out of sediments. In addition to locating new sources of hydrocarbon fuels, exploration of these communities frequently reveals species that are new to science and provides information on ecology and biodiversity that is needed to protect these unique and sensitive environments.

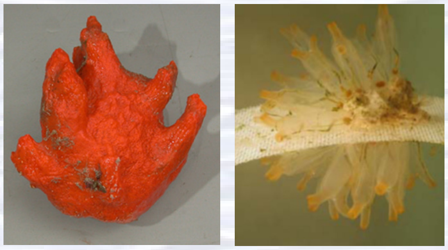
For more information about methane hydrates, visit http://oceanexplorer.noaa.gov/explorations/03windows/welcome.html. For more information about protecting sensitive environments as part of exploration and development of ocean mineral resources, visit http://oceanexplorer.noaa.gov/explorations/07mexico/welcome.html.

### Human Health

Improving human health is another motive for ocean exploration. Almost all drugs derived from natural sources come from terrestrial plants. But recent explorations have found that some marine invertebrates such as sponges, tunicates, ascidians, bryozoans, and octocorals can also produce powerful drug-like substances. Many of these are sessile (non-moving), bottom-dwelling animals that do not appear particularly impressive; yet, they produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. The potential for discovering important new drugs from deep-ocean organisms is even greater when one considers that most of Earth's seafloor is still unexplored, and deep-sea explorations routinely find species that have never been seen before.

**For recommended Lesson Plans about Human Health and Drugs from the Sea, please see page 15.**

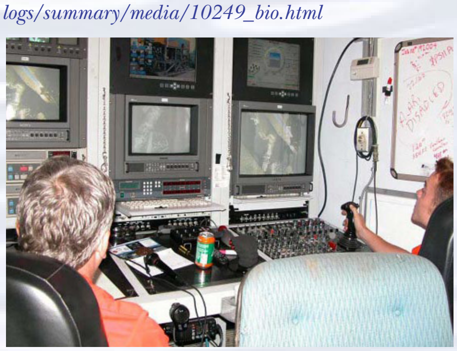
Chemicals produced by marine animals that may be useful in treating human diseases include:



Though they may be visually unimpressive, Forcepia sponges (left) are the source of lasonolides and tunicates (right) are the source of ecteinascidin, potential new drugs for treating cancer. Image credit: NOAA.
*http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/lasonolide1_hirez.jpg*
*http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/figure4_hirez.jpg*

A sponge from the Verongida family, collected during the 2003 Deep Sea Medicines expedition. Image credit: NOAA.
*http://oceanexplorer.noaa.gov/explorations/03/bio/logs/sep10/media/verongida_sponge_600.jpg*

Dr. Shirley Pomponi, one of three co-principal investigators on the 2003 Deep Sea Medicines expedition, removing a bright yellow sponge from a seafloor sample. Image credit: NOAA.
*http://oceanexplorer.noaa.gov/explorations/03bio/logs/summary/media/10249_bio.html*



Pilot and co-pilot maneuver arms and cameras on an ROV to collect samples to be tested for drug activity. Image credit: T. Piper, NOAA OE.
*http://oceanexplorer.noaa.gov/explorations/03bio/logs/sept13/media/greg_lucasinvan_600.jpg*

***Ecteinascidin*** – Extracted from tunicates; being tested in humans for treatment of breast and ovarian cancers and other solid tumors; acts by blocking transcription of DNA

***Topsentin*** – Extracted from the sponges *Topsentia genitrix*, *Hexadella* sp., and *Spongosorites* sp.; anti-inflammatory agent; mode of action not certain

***Lasonolide*** – Extracted from the sponge *Forcepia* sp.; anti-tumor agent; acts by binding with DNA

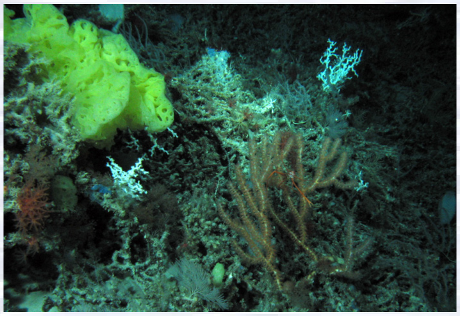
***Discodermalide*** – Extracted from deep-sea sponges belonging to the genus *Discodermia*; anti-tumor agent; acts by interfering with microtubule networks (you may want to review the function of microtubules here)

***Bryostatin*** – Extracted from the bryozoan *Bugula neritina*; potential treatment for leukemia and melanoma; acts as a differentiating agent, forcing cancer cells to mature and thus halting uncontrolled cell division

***Pseudopterosins*** – Extracted from the octocoral *Pseudopterogorgia elisabethae* (sea whip); anti-inflammatory and analgesic agents that reduce swelling and skin irritation and accelerate wound healing; acts as an inhibitor of phospholipase A, which is a key enzyme in inflammatory reactions

***ω-conotoxin MVIIA*** – Extracted from the cone snail *Conus magnus*; potent pain-killer; acts by interfering with calcium ion flux, thereby reducing the release of neurotransmitters

A striking feature of this list is that all of the organisms (except the cone snail) are sessile (non-moving) invertebrates. To date, this has been true of most marine invertebrates that produce pharmacologically-active substances. Several reasons have been suggested to explain why sessile marine animals are particularly productive of potent chemicals. One possibility is that they use these chemicals to repel predators, since they are basically "sitting ducks." Since many of these species are filter feeders, and consequently are exposed to all sorts of parasites and pathogens in the water, they may use powerful chemicals to repel parasites or as antibiotics against disease-causing



Space is at a premium in many benthic habitats. Image credit: Brooke et al, NOAA-OE, HBOI.
*http://oceanexplorer.noaa.gov/explorations/05deepcorals/logs/hires/diverse_habitat_hires.jpg*

Many coral reefs are threatened by simultaneous impacts from pollution, rising temperatures, ocean acidification, and overfishing. Image credit: Thomas K. Gibson, Florida Keys National Marine Sanctuary.
*http://www.photolib.noaa.gov/bigs/reef2583.jpg*

organisms. Competition for space may explain why some of these invertebrates produce anti-cancer agents. If two species are competing for the same piece of bottom space, it would be helpful to produce a substance that would attack rapidly dividing cells of the competing organism. Since cancer cells often divide more rapidly than normal cells, the same substance might have anti-cancer properties.

For more information about drugs from the sea, visit http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html.

**Ocean Health**

"Anyone familiar with the state of the world's oceans would have a hard time feeling optimistic. From coral reefs overwhelmed by coastal runoff to tiny but ecologically-vital plankton that are suffering from climate change, the diversity of sea life is fading." (Allsopp, et al., 2007).

The health of Earth's ocean is simultaneously threatened by over-exploitation of large species, destruction of benthic habitats, invasive species, rising temperatures, and pollution (Jackson, 2008). Recently, another stress has been recognized: ocean acidification. For many years, carbon dioxide in Earth's atmosphere has been increasing. Regardless of the reasons for this increase and the possible connection with climate change, dissolved carbon dioxide in the ocean has increased along with atmospheric $CO_2$. More dissolved carbon dioxide means a lower ocean pH. This, in turn, leads to a decrease in carbonate ions that are essential to the process of calcification through which many organisms produce shells and other skeletal structures. In addition to corals, shellfish, echinoderms, and many marine plankton also build body parts through calcification. Pteropods are planktonic snails that are an important component of food chains in high-latitude regions, and have been shown to have pitted or partially dissolved shells in waters where carbonate ions are depleted.

For more information about ocean pH and carbon dioxide, see pages 20-22 in the Diving Deeper section.

On June 5, 2008, NOAA Oceanographer Richard A. Feely told the U.S. House of Representatives Subcommittee on Energy and Environment that the ocean currently absorbs 22 million tons of carbon dioxide daily, and that scientists estimate the pH of ocean surface waters has fallen by about 0.11 units from an average of

*Limacina helicina*, a free-swimming planktonic snail. These snails, known as pteropods, form a calcium carbonate shell and are an important food source in many marine food webs. As levels of dissolved $CO_2$ in sea water rise, skeletal growth rates of pteropods and other calcium-secreting organisms will be reduced due to the effects of dissolved $CO_2$ on ocean acidity. Image credit: Russ Hopcroft, UAF/NOAA.
*http://www.noaanews.noaa.gov/stories2006/images/pteropod-limacina-helicina.jpg*

**For recommended Lesson Plans about Ocean Health, please see page 15.**

about 8.21 to 8.10 since the beginning of the industrial revolution. Feely also said that if carbon dioxide emissions continue according to predictions, the surface water pH will decrease to about 7.8 – 7.9 by the end of the century. "To put this in historical perspective, the resulting surface ocean pH would be lower than it has been for more than 20 million years," he said.

"Life will find a way," according to chaos theorist Ian Malcolm in *Jurassic Park* (Crichton, 1990). But the question is, "Which life?" Deep-sea explorers often find biological organisms thriving in conditions that would be extremely hostile to humans. But this does not mean that species can simply adapt to stresses from falling pH, rising sea levels and temperatures, pollution and overfishing. We urgently need to learn more about ocean ecosystems and how they affect the rest of our planet. This is one of the most important modern reasons for ocean exploration. Without a doubt, human curiosity, the desire to understand our world, and the excitement of discovery are still among the reasons we explore Earth's ocean; but we also explore to survive.

### Research

Expeditions to the unexplored ocean can help focus research into critical geographic and subject areas that are likely to produce tangible benefits. Telepresence technology aboard the *Okeanos Explorer* allows many researchers to participate at a fraction of the cost of traditional expeditions, as well as opportunities for students and the general public to have a first-hand look at the processes of scientific research.

### Technological Innovation

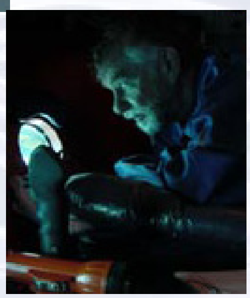
The challenges of working in the extremely hostile environments of the deep-ocean are an ongoing stimulus for technology innovation and development.

### Science Education

Ocean exploration can help inspire new generations of youth to seek careers in science, and offers vivid examples of how concepts of biology, physical science, and Earth science are useful in the real world. Similarly, the challenges of exploring the deep-ocean can provide the basis for problem-solving instruction in technology and engineering. Ocean exploration also provides an engaging context for improving ocean literacy; understanding how the ocean influences our lives, and how we influence the ocean. Widespread ocean literacy is increasingly vital as we confront issues such as ocean health and climate change.

Dr. Amy Baco-Taylor, Deep-sea biologist.
Image credit: Tyler Fox.
*http://oceanexplorer.noaa.gov/edu/oceanage/04baco_taylor/welcome.html*

Hugo Marrero, Submersible Pilot, Harbor Branch Oceanographic Institute.
*http://oceanexplorer.noaa.gov/edu/oceanage/06marrero/welcome.html*



Dr. Roy Cullimore, Microbiologist.
Image credit: Jeremy Weirich.
*http://oceanexplorer.noaa.gov/edu/oceanage/04cullimore/welcome.html*

### Who Are Today's Ocean Explorers? [OceanAGE]

Ocean exploration requires new ways of thinking and close collaboration among biologists, chemists, climatologists, computer programmers, educators, engineers, geologists, meteorologists, and physicists, anthropologists, and many other fields of expertise. Through the Ocean Explorer OceanAGE Careers Web page http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html, marine explorers provide students with first-hand knowledge of exciting careers through live interviews, profiles, and mission logs. Web forums and Web chats with selected experts are also offered throughout the year. Career profiles include:

- Deep-sea Biologist – Amy Baco-Taylor
- Fish Ecologist – Peter Auster
- Geophysicist – Bob Embley
- Marine Archaeologist – Jeremy Weirich
- Marine Ecologist – Peter Etnoyer
- Marine Mammal Biologist – Kristin Laidre
- Microbiologist – Roy Cullimore
- Natural Products Biologist – Shirley Pomponi
- NOAA Corps Officer – Shannon Ristau
- Oceanographer – Robert Ballard
- Submersible Pilot – Hugo Marrero

Note that many of the topics discussed above apply to more than one "reason to explore." Methane hydrates, for example, are relevant to climate change as a potential source of a greenhouse gas that could accelerate trends toward warmer temperatures. Similarly, pH changes discussed under "ocean health" are also linked to climate change since increased dissolved carbon dioxide in the ocean is the result of increased carbon dioxide in the atmosphere that may be partially responsible for observed changes in Earth's climate. The same issues are also relevant to drugs from the sea, since warmer temperatures and changes in ocean circulation patterns are among the stressors that threaten some of the marine organisms that produce pharmacologically-active substances.

The key point here is that the ocean processes do not operate in isolation; they interact and affect each other in ways that we are just beginning to understand. We separate these topics as individual examples of reasons to explore, and for improved clarity in an introductory discussion; but it is important to realize that the ocean is an integrated system—individual organisms and processes always interact with many others, and the whole is much more complex than the sum of the parts.

## Key Images and Video Resources

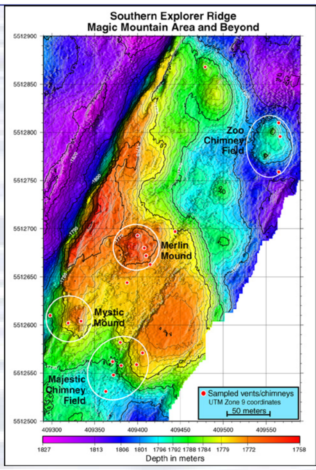
*Many expeditions funded through NOAA's Office of Ocean Exploration and Research produce photo and video logs that are included on the Ocean Explorer Web site. Following are links to specific photo and video logs that are particularly relevant to key topics discussed in this lesson. You can also browse images by subject in the Ocean Explorer Gallery (http://oceanexplorer.noaa.gov/gallery/gallery.html).*

2003 Medicines from the Deep Sea Expedition:
http://oceanexplorer.noaa.gov/explorations/03bio/logs/photolog/photolog.html *(Drugs from the sea)*

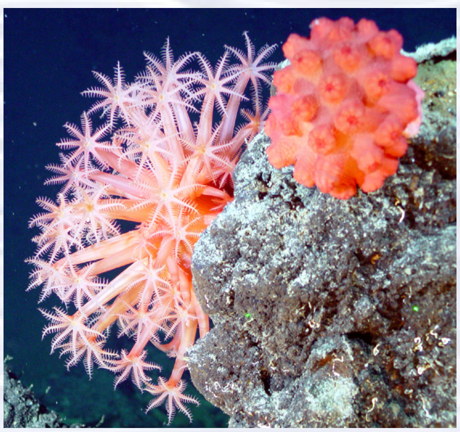
2003 Windows to the Deep Expedition:
http://oceanexplorer.noaa.gov/explorations/03windows/logs/photolog/photolog.html *(Methane, cold seep communities)*

2005 GalAPAGoS: Where Ridge Meets Hotspot Expedition:
http://oceanexplorer.noaa.gov/explorations/05galapagos/logs/photolog/photolog.html *(Hydrothermal vent communities)*

2006 Davidson Seamount: Exploring Ancient Coral Gardens Expedition:




Bathymetric map of the Magic Mountain area on Explorer Ridge, part of the Submarine Ring of Fire. Visit *http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html* for a virtual tour of the Magic Mountain site. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/02fire/logs/hirez/magic-hires.jpg*



Mushroom Coral; a deep-sea soft coral growing on top of a vent chimney formed by hydrothermal vents on the Submarine Ring of Fire. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/02fire/logs/hirez/R664_DSC_octocorals_96.jpg*

http://oceanexplorer.noaa.gov/explorations/06davidson/logs/photolog/photolog.html *(Deep-water corals and other species)*

2006 Expedition to the Deep Slope:
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/photolog/photolog.html *(Seep communities)*

2006 Ring of Fire Expedition:
http://www.oceanexplorer.noaa.gov/explorations/06fire/logs/photolog/photolog.html *(Underwater volcanoes, carbon dioxide venting)*

New Zealand American Submarine Ring of Fire 2007 Expedition:
http://oceanexplorer.noaa.gov/explorations/07fire/logs/photolog/photolog.html *(Underwater volcanoes, exploration technology)*

*Lophelia* II 2008: Deepwater Coral Expedition: Reefs, Rigs and Wrecks:
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/photolog/photolog.html *(Deep-water communities)*

## Recommended Lesson Plans for Further Exploration of Key Topics

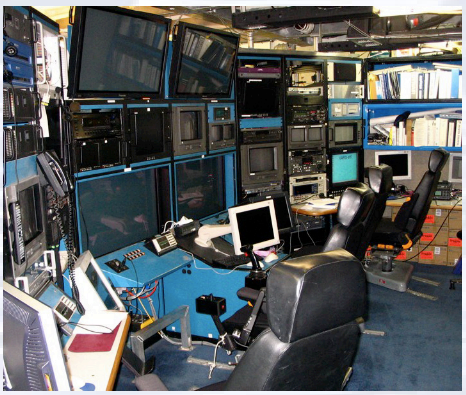
*To access these lesson plans, go to* http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html.

### Lesson for Initial Inquiry:

**To Boldly Go…** *(Grades 7-8; adaptations for 5-6 & 9-12)*
This is the introductory lesson for the "Why Do We Explore?" theme to guide student inquiries for an overview of key topics. Students will discuss why scientists believe there are important undiscovered features and processes in Earth's ocean, discuss at least three motives that historically have driven human exploration, explain why ocean exploration is relevant to climate change, energy, human health, ocean health, innovation, research, and ocean literacy; and discuss at least three benefits that might result from ocean exploration.

*Hands-on activity:* Ocean Exploration Learning Shapes

Swimmers recovering Deep Submergence Vehicle *Alvin* after a dive on Manning Seamount off the Carolina coast during the 2003 Windows to the Deep Expedition. Image credit: C. Martinez, NOAA
*http://oceanexplorer.noaa.gov/technology/subs/alvin/media/alvin_recovery_water_600.jpg*



The control room stations for the ROV Tiburon used on the 2006 Davidson Seamount Expedition. From left to right, the stations are: Co-pilot, Pilot, Science, Annotation, and Navigation. Image credit: NOAA/MBARI 2006. For more information, please visit *http://oceanexplorer.noaa.gov/explorations/06davidson/logs/feb02/feb02.html*
*http://oceanexplorer.noaa.gov/explorations/06davidson/logs/hires/control_room_hires.jpg*

The 2006 Tracking Narwhals in Greenland Expedition used satellite-linked time-depth-temperature recorders to track whale movements, diving behavior, and ocean temperature structure during the fall narwhal migration from north Greenland to Baffin Bay. This information is needed to help understand how Arctic climate change may affect the deep-ocean thermohaline circulation, sometimes known as the "global conveyor belt." Image credit: Mads Peter Heide-Jorgensen.
*http://oceanexplorer.noaa.gov/explorations/06arctic/background/hires/male_narwhals_hires.jpg*

## Other Lessons for Further Exploration of Key Topics:

*While each lesson is targeted toward a specific grade level, most can be adapted for use in other grades as well.*

### • Ocean Exploration

*Grades 5-6*

**Journey to the Unknown**

Students will experience the excitement of discovery and problem-solving to learn what organisms could live in extreme environments in the deep-ocean, and will understand the importance of ocean exploration.

*Hands-on activity:* Posterize images and construct an ultraviolet LED poster illuminator

*Grades 7-8*

**Come on Down!**

Students will research the development and use of research vessels/vehicles used for deep-ocean exploration, calculate the density of objects by determining the mass and volume, and construct a device that exhibits neutral buoyancy.

*Hands-on activity:* Construct an electronic force sensor

*Grades 9-12*

**Calling All Explorers**

Students will learn what it means to be an explorer, both modern and historic, recognize that not all exploration occurs on land; understand the importance of curiosity, exploration, and the ability to document what one studies; gain insight into the vastness of unexplored places in the deep sea; and gain appreciation of science mentors and role models.

*Hands-on activity:* "Your Own Expedition of Discovery" (geocaching)

### • Climate Change

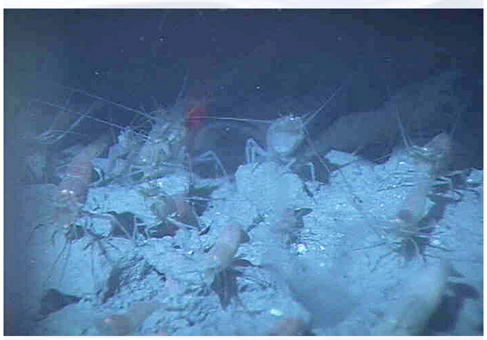
*Grades 5-6*

**The Methane Circus**

Students will describe the overall events that occurred during the "Cambrian explosion," explain how methane hydrates may contribute to global warming, and describe the reasoning behind hypotheses that link methane hydrates with the Cambrian explosion.

*Hands-on activity:* Create model fossils of organisms that appeared during the Cambrian explosion

Researchers lower a CTD (to measure conductivity, temperature, and depth) through a hole chopped through the sea ice. Image credit: Kristin Laidre.
*http://oceanexplorer.noaa.gov/explorations/06arctic/logs/hires/figure7_hires.jpg*



Ice shrimp congregate beneath a overhang that caps a methane hydrate deposit studied during the 2003 Windows to the Deep expedition. Image credit: Woods Hole Oceanographic Institution.
*http://oceanexplorer.noaa.gov/explorations/03windows/logs/jul30/media/iceshrimp_600.jpg*

*Grades 7-8*

**Where Have All the Glaciers Gone?**

Students will describe how climate change is affecting sea ice, vegetation, and glaciers in the Arctic region; explain how changes in the Arctic climate can produce global impacts; and be able to provide three examples of such impacts. Students will also explain how a given impact resulting from climate change may be considered 'positive' as well as 'negative', and will be able to provide at least one example of each.

*Hands-on activity:* Make a photocube showing changes in glaciers

*Grades 9-12*

**History's Thermometers**

Students will explain the concept of paleoclimatological proxies, learn how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about climate and climate change in the geologic past.

*Hands-on activity:* Make a scientific poster

- **Energy**

*Grades 5-6*

**Animals of the Fire Ice**

Students will define and describe methane hydrate ice worms and hydrate shrimp, infer how methane hydrate ice worms and hydrate shrimp obtain their food, and infer how methane hydrate ice worms and hydrate shrimp may interact with other species in the biological communities of which they are part.

*Hands-on activity:* Model a methane hydrate community

*Grades 7-8*

**Oceans of Energy**

Students will describe forms of energy, explain how each form is used by humans, and discuss at least three ways that energy can be obtained from the ocean.

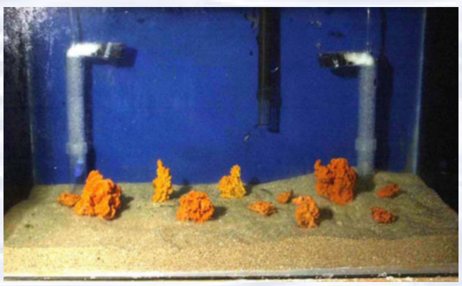
*Hands-on activity:* Build a simple turbine

*Grades 9-12*

**What's the Big Deal?**

Students will define methane hydrates, describe where these substances are typically found, explain how they are believed to be formed, describe at least three ways in which methane hydrates could have a direct impact on their own lives, and describe how additional knowledge of methane hydrates could provide human benefits.

Thousands of chemicals with pharmaceutical potential have been identified from marine organisms, and more have been found in sponges than any other group. One of the challenges for developing this potential is to find ways to supply organisms that produce these chemicals without damaging ecosystems or depleting natural resources. Here, deep-water sponges have been transplanted to an experimental aquaculture farm at a depth of 60 ft. Pieces of sponges are placed inside mesh bags and anchored to the bottom. They are measured for growth and the production of bioactive chemicals. Image credit: NOAA.
*http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/figure2_hirez.jpg*



Growth and feeding studies on sponges are conducted under controlled conditions in a lab at Harbor Branch Oceanographic Institution. Image credit: NOAA.
*http://oceanexplorer.noaa.gov/explorations/03bio/logs/hirez/figure3_hirez.jpg*

*Hands-on activity:* Construct a model of a methane hydrate molecule

## • Human Health

### *Grades 5-6*

**MICROFRIENDS**

Students will describe at least three ways in which microorganisms benefit people, describe aseptic procedures, and obtain and culture a bacterial sample on a nutrient medium.

*Hands-on activity:* Bacteria culture

### *Grades 7-8*

**WHAT KILLED THE SEEDS?**

Students will explain and carry out a simple process for studying the biological effects of chemicals and will be able to infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

*Hands-on activity:* Bioassay

### *Grades 9-12*

**WATCH THE SCREEN**

Students will be able to explain and carry out a simple process for screening natural products for biological activity, and will be able to infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

*Hands-on activity:* Screening plant products for antibacterial properties

## • Ocean Health

### *Grades 5-6*

**BUILD YOUR OWN OCEAN ECOSYSTEM**

Students will identify key functions that are present in healthy ocean ecosystems, and discuss how these functions are met by living and non-living components in a model aquatic ecosystem.

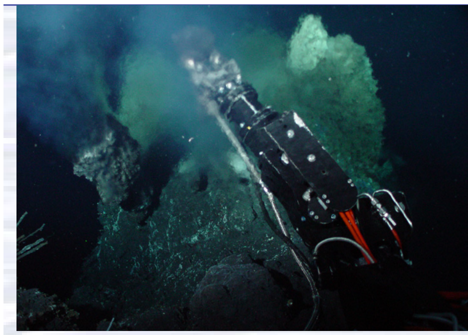
*Hands-on activity:* Build an ecosystem in a bottle

### *Grades 7-8*

**STRESSED OUT!**

Students will identify stresses that threaten the health of ocean ecosystems, explain natural and human-caused processes that contribute to these stresses, and discuss actions that may be taken to reduce them.

*Hands-on activity:* Experiments with a tabletop biosphere



Gases and fluids from deep-sea volcanoes and hydrothermal vents can have significant effects on the pH of nearby ecosystems. Here, remotely operated vehicle ROPOS samples hot fluids from a black smoker vent on the Submarine Ring of Fire. Image credit: NOAA/OER. *http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul31/media/ropossample.html*

### *Grades 9-12*

**Off Base**

Students will define pH and buffer, explain in general terms the carbonate buffer system of seawater, explain Le Chatelier's Principle, predict how the carbonate buffer system of seawater will respond to a change in concentration of hydrogen ions, identify how an increase in atmospheric carbon dioxide might affect the pH of the ocean, and discuss how this alteration in pH might affect biological organisms.

*Hands-on activity:* Experiments with pH buffers

## Other Resources

*The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of publication, but the linking sites may become outdated or non-operational over time.*

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book – A free printable book for home or school introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

Allsopp, M., R. Page , P. Johnston , and D. Samtillo. 2007. *Oceans in Peril*. Worldwatch Report 174. Worldwatch Institute, Washington, DC. 56 pp.

Jackson, J. B. C. 2008. Ecological extinction and evolution in the brave new ocean. Proceedings of the National Academy of Sciences, August 12, 2008 Vol. 105 No. Supplement 1 11458-11465. Abstract available online at http://www.pnas.org/content/105/suppl.1/11458.

http://www.ucar.edu/communications/Final_acidification.pdf – "Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research;" Report from a Workshop Sponsored by the National Science Foundation, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey

Havenhand, J.N., F.-R. Buttler, M.C. Thorndyke, J.E. Williamson. 2008. Near-future levels of ocean acidification reduce fertilization success in a sea urchin. Current Biology, 18:R651-R652.

http://www.terrain.org/articles/21/burns.htm – Article on ocean acidification http://www.oceana.org/climate/impacts/acid-oceans/ – Oceana article on ocean acidification

http://www.usgcrp.gov/usgcrp/documents/mmbralmanac.html – "Is the Climate Changing? Indeed It Is," by Michael MacCracken, Director of the Office of the U.S. Global Change Research Program, and Tom Karl, Senior Scientist, National Climatic Data Center, NOAA

http://nsidc.org/data/glacier_photo/repeat_photography.html – Repeat Photography of Glaciers; photographs taken from the same vantage point, but years apart in time, that provide striking visual evidence of climate change; from the National Snow and Ice Data Center

http://oceanexplorer.noaa.gov/history/history.html – NOAA's 200-year history of ocean exploration

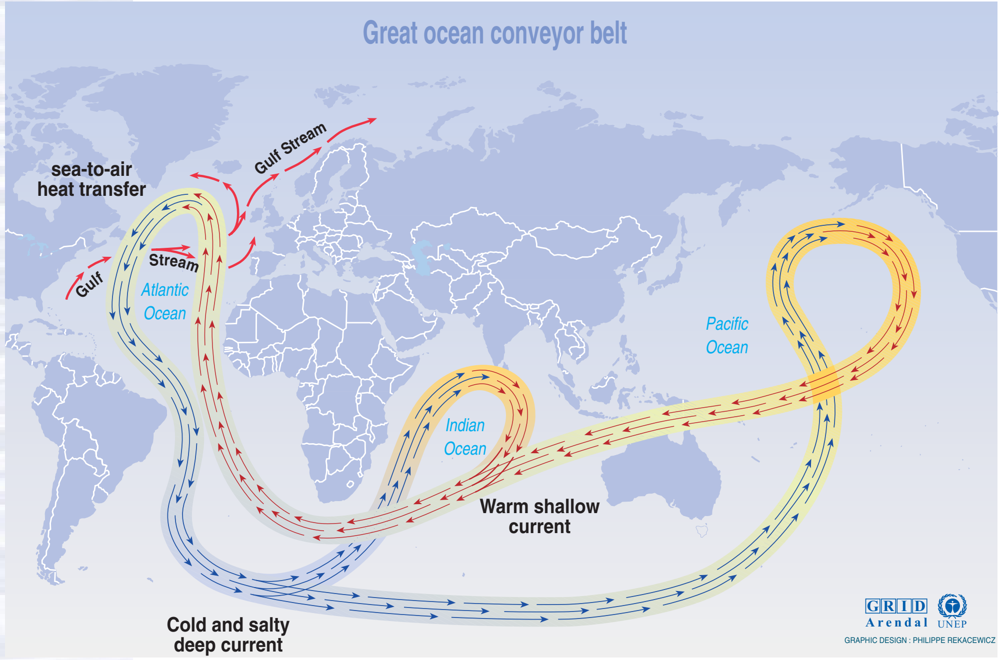
http://oceanexplorer.noaa.gov/history/quotes/explore/explore.html – Quotations about "Why Explore?"

http://www.arctic.noaa.gov/essay_bond.html – "Why is the Arctic important?" by Nick Bond, Jim Overland and Nancy Soreide, NOAA Pacific Marine Environmental Laboratory

Kramer, P. 2003. Synthesis of coral reef health indicators for the Western Atlantic: Results of the AGRRA program (1997-2000). In Lang, J.C. (ed.) 2003. Status of coral reefs in the Western Atlantic: results of initial surveys, Atlantic and Gulf Rapid Reef Assessment (AGRRA) program. Atoll Research Bulletin 496. 639 pp. Washington, DC. (http://www.botany.hawaii.edu/faculty/duffy/arb/496/Synthesis.pdf)

Crichton, M. 1990. *Jurassic Park*. Ballantine Books, New York.

http://www.pmel.noaa.gov/CO2/OA/index.html – Ocean acidification Web page from NOAA's Pacific Marine Environmental Laboratory




World ocean thermohaline circulation (THC) is driven primarily by the formation and sinking of deep water in the Norwegian Sea. When salinity decreases because of excess precipitation, runoff, or ice melt, the conveyor belt will weaken or even shut down. Variations in the THC may lead to climate change in Europe and also affect other areas of the global ocean.
Source: *http://www.grida.no/publications/vg/climate/page/3085.aspx*; data from Climate Change 1995 – Impacts, adaptations and mitigation of climate change: Scientific-Technical Analyses. Contribution of Working Group 2 to the Second Assessment Report of the Intergovernmental Panel on Climate Change. United Nations Environment Programme and World Meteorological Organization. Cambridge Univeristy Press. 1996. Cartographer/Designer: Philippe Rekacewicz, UNEP/GRID-Arendal.
*http://maps.grida.no/library/files/storage/31new.pdf*

## Diving Deeper: Additional Information about Key Topics

*This section provides additional details and discussion of selected topics mentioned in "Background Information."*

**The Deep-ocean Thermohaline Circulation** *(Climate Change, pg 4)*
The deep-ocean thermohaline circulation is driven by changes in seawater density. Two factors affect the density of seawater: temperature (the "thermo" part) and salinity (the "haline" part). Major features of the THC include:

- In the Northeastern Atlantic Ocean, atmospheric cooling increases the density of surface waters. Decreased salinity due to freshwater influx partially offsets this increase (since reduced salinity lowers the density of seawater), but temperature has a greater effect, so there is a net increase in seawater density. The formation of sea ice may also play a role as freezing removes water but leaves salt behind causing the density of the unfrozen seawater to increase. The primary locations of dense water formation in the North Atlantic are the Greenland-Iceland-Nordic Seas and the Labrador Sea.
- The dense water sinks into the Atlantic to depths of 1000 m and below, and flows south along the east coasts of North and South America.
- As the dense water sinks, it is replaced by warm water flowing north in the Gulf Stream and its extension, the North Atlantic Drift (note that the Gulf Stream is primarily a wind driven current, but portions of its circulation—the North Atlantic Drift—are also part of the THC).

- The deep south-flowing current combines with cold, dense waters formed near Antarctica, and flows from west to east in the Deep Circumpolar Current. Some of the mass deflects to the north to enter the Indian and Pacific Oceans.
- Some of the cold water mass is warmed as it approaches the equator, causing density to decrease. Upwelling of deep waters is difficult to observe, and is believed to occur in many places, particularly in the Southern Ocean in the region of the Antarctic Circumpolar Current.
- In the Indian Ocean, the water mass gradually warms and turns in a clockwise direction until it forms a west-moving surface current that moves around the southern tip of Africa into the South Atlantic Ocean.
- In the Pacific, the deepwater mass flows to the north on the western side of the Pacific basin. Some of the mass mixes with warmer water, warms, and dissipates in the North Pacific. The remainder of the mass continues a deep, clockwise circulation. A warm, shallow current also exists in the Pacific, which moves south and west, through the Indonesian archipelago, across the Indian Ocean, around the southern tip of Africa, and into the South Atlantic.
- Evaporation increases the salinity of the current, which flows toward the northwest, joins the Gulf Stream, and flows toward the Arctic regions where it replenishes dense sinking water to begin the cycle again.

The processes outlined above are greatly simplified. In reality, the deep-ocean THC is much more complex, and is not fully understood. Our understanding of the connections between the deep-ocean THC and Earth's ecosystems is similarly incomplete, but most scientists agree that:

- The THC affects almost all of the world's ocean (and for this reason, it is often called the "global conveyor belt");
- The THC plays an important role in transporting dissolved oxygen and nutrients from surface waters to biological communities in deep water; and
- The THC is at least partially responsible for the fact that countries in northwestern Europe (Britain and Scandinavia) are about 9°C warmer than other locations at similar latitudes.

In recent years, changes in the Arctic climate have led to growing concerns about the possible effects of these changes on the deep-ocean THC. In the past 30 years, parts of Alaska and Eurasia have warmed by about six degrees Celsius. In the last 20 years, the extent of Arctic sea ice has decreased by 5%, and in some areas, sea ice thickness has decreased by 40%. Overall, the Arctic climate is warming more rapidly than elsewhere on Earth. Reasons for this include:

- When snow and ice are present, as much as 80% of solar energy that reaches Earth's surface is reflected back into space. As snow and ice melt, surface reflectivity (called "albedo") is reduced, so more solar energy is absorbed by Earth's surface;
- Less heat is required to warm the atmosphere over the Arctic because the Arctic atmosphere is thinner than elsewhere http://oceanexplorer.noaa.gov/explorations/06arctic/logs/leg1_summary/media/slideshow/slideshow.html#;
- With less sea ice, the heat absorbed by the ocean in summer is more easily transferred to the atmosphere in winter.

Dense water sinking in the North Atlantic Ocean is one of the principal forces that drives the circulation of the global conveyor belt. Since an increase in freshwater inflow (such as from melting ice) or warmer temperatures in these areas would weaken the processes that cause seawater density to increase, these changes could also weaken the global conveyor belt.

**pH and Carbon Dioxide** *("Ocean Health," page 9)*
For more information about ocean acidification, visit the Web page for the Ocean Explorer 2008 Reefs, Rigs, and Wrecks Expedition, http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/sept24.html.

***What Do pH Numbers Mean?***
An "acid" is commonly defined as a chemical that releases hydrogen ions (abbreviated $H^+$). The pH (which stands for "power of hydrogen") of a solution is defined as the negative logarithm of the hydrogen ion concentration in moles per liter.
So,

$$\mathbf{pH = -\log [H^+]}$$

where brackets are understood to mean "concentration."
The logarithm of a number x is the power to which another number called the "base" must be raised to produce x. So, the logarithm of 1000 to the base 10 is 3 because 10 raised to the power of 3 is equal to 1000. Where pH is concerned, the base is always 10.

If a solution has a hydrogen ion concentration of $1 \times 10^{-7}$ moles/liter, the logarithm of this concentration is -7, and the pH is 7. The pH scale ranges from 0 to 14, which corresponds to a hydrogen ion concentration range of 1.0 mole/liter to 1 x

$10^{-14}$ mole/liter. A pH of 7 is considered neutral. A pH below 7 (higher hydrogen ion concentration) is acidic; a pH above 7 (lower hydrogen ion concentration) is basic.

A decrease of 0.1 pH unit may not seem like much, until we remember that this is a logarithm. So a pH of 8.2 corresponds to a hydrogen ion concentration of:

$1 \times 10^{-8.2}$ moles/liter = 0.00000000631 moles/liter
(10 raised to the -8.2 power)

and a pH of 8.1 corresponds to a hydrogen ion concentration of:

$1 \times 10^{-8.1}$ moles/liter = 0.00000000794 moles/liter

so a drop of 0.1 pH unit represents a 25.8% increase in the concentration of hydrogen ions.

Note that while the term "ocean acidification" is commonly used, the ocean is not expected to actually become acidic (which would mean that the pH was below 7.0). "Acidification" in this case only means that the pH is declining.

### *The Carbonate Buffer System*

pH is a measure of acidity, which is the concentration of hydrogen ions; increasing hydrogen ions causes increased acidity. A pH of 7 is considered neutral; a pH below 7 is acidic; a pH above 7 is basic. Dissolved chemicals cause seawater to act as a pH buffer; that is, seawater tends to resist changes in pH. This Carbonate Buffer System is described by the following equation:

**The Carbonate Buffer System Equation**

| $CO_2$ | + | $H_2O$ | < > | $H_2CO_3$ | < > | $H^+$ | + | $HCO_3^-$ | < > | $H^+$ | + | $CO_3^{2-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| carbon dioxide | | water | | carbonic acid | | hydrogen ion | | bicarbonate ion | | hydrogen ion | | carbonate ion |

This equation shows that carbon dioxide dissolves in seawater to form carbonic acid, a weak acid. Most of the carbonic acid normally dissociates to form hydrogen ions, bicarbonate ions, and carbonate ions. Carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions are all present in normal seawater, although not in the same concentrations (bicarbonate and carbonate concentrations are much higher than carbon dioxide and carbonic acid). When these chemicals are in equilibrium, the pH of seawater is about 8.1 – 8.3 (slightly basic). More dissolved carbon dioxide causes an increase in hydrogen ions and a lower ocean pH. But the pH change in seawater is less than if the same amount of carbon dioxide were dissolved in fresh water because the carbonate buffer system in seawater removes some of the added hydrogen ions from solution.

But the chemical reactions that take place in this buffer system have another consequence. Bicarbonate ions form much more readily than carbonate ions, so added hydrogen ions tend to react with carbonate ions to form bicarbonate. So, adding hydrogen ions to seawater causes a decrease in carbonate ions; and carbonate ions are essential to the process of calcification through which many organisms produce shells and other skeletal structures.

## Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.
Please send your comments to:
oceanexeducation@noaa.gov

## For More Information

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